RELIABILITY CONCEPTS

(05)

OBJECTIVES

Be able to answer (or know):

- **How does probability theory relate to reliability? What are the mathematical relationships?**
- **Know what defines a mission success.**
- **What is inherent reliability and what are the external factors that affect it?**
- **To access reliability, what needs to be evaluated?**
- **What is the difference between failure mode, failure cause, failure mechanism and failure stress.**
- **Understand how failure rate, λ, MTBF and reliability relate to each other; under what conditions?**

OUTLINE

- Probability Theory
- Reliability Concepts
- Failure Physics
- Failure Rate and MTBF

PROBABILITY THEORY:

- **RELIABILITY VALUES ARE USUALLY EXPRESSED AS PROBABILITIES**
- **In the normal distribution problem, saying there is a 30% possibility of picking a valve which will fail in less than x miles is the same as saying there is a probability of .3 of selecting a valve which will fail in less than x miles.**

PROBABILITY -- DEFINITION

- **If an event can occur in A different ways, all of which are considered equally likely, and if a certain number B of the events are considered successful or favorable, the ration B/A is called the probability of the event.**

PROBABILITY THEORY
Definitions

- Priori reliability
  - Predictions made before the event.
- Posteriori reliability
  - Observed reliability
- Independence
  - Two events A and B are independent if the occurrence or nonoccurrence of either of them does not effect the probability of the occurrence of the other.
- Mutually exclusive
  - Events A and B are mutually exclusive if they both can not occur simultaneously.

Reliability of a Coin

- The probability of either side of the coin landing face up is equal and there are two possible outcomes. Therefore the probability of heads or tails is: 1/2 or 0.5
- As the number of trials goes up the actual outcome will approach the predicted outcome.

EVENTS EXPRESSED AS PROBABILITIES

- **Probability of 0.50 (or 1/2) of getting a head in a single toss of a coin.**
- **Probability of 0.167 (or 1/6) of getting a 3 in a single roll of a die (neglecting weight differences of various sides).**
- **Probability of 0.077 (or 1/13) of drawing an ACE out of a deck of cards in one draw.**
- **Probability of 0.019 (or 1/52) of drawing a QUEEN of HEARTS out of a deck of cards in one draw.**
- **Probability of 0.20 (or 1/5) of drawing a black marble out of a bag with a black, red, white, yellow and green marble in it with a single pick.**

PROBABILITY THEOREMS

- **Theorem 1 - if the probability of success is R, the probability of failure Q is equal to 1-R.**
- **Calculating Values:**
  - **Probability of 1/2 of NOT getting a head in a single toss of a coin.**
  - **Probability of 5/6 of NOT getting a 3 in a single roll of a die (neglecting weight differences of various sides).**
  - **Probability of 12/13 of NOT drawing an ACE out of a deck of cards in one draw.**
  - **Probability of 51/52 of NOT drawing a QUEEN of HEARTS out of a deck of cards in one draw.**
  - **Probability of 4/5 of NOT drawing a black marble out of a bag with a black, red, white, yellow and green marble in it with a single draw.**

PROBABILITY THEOREMS

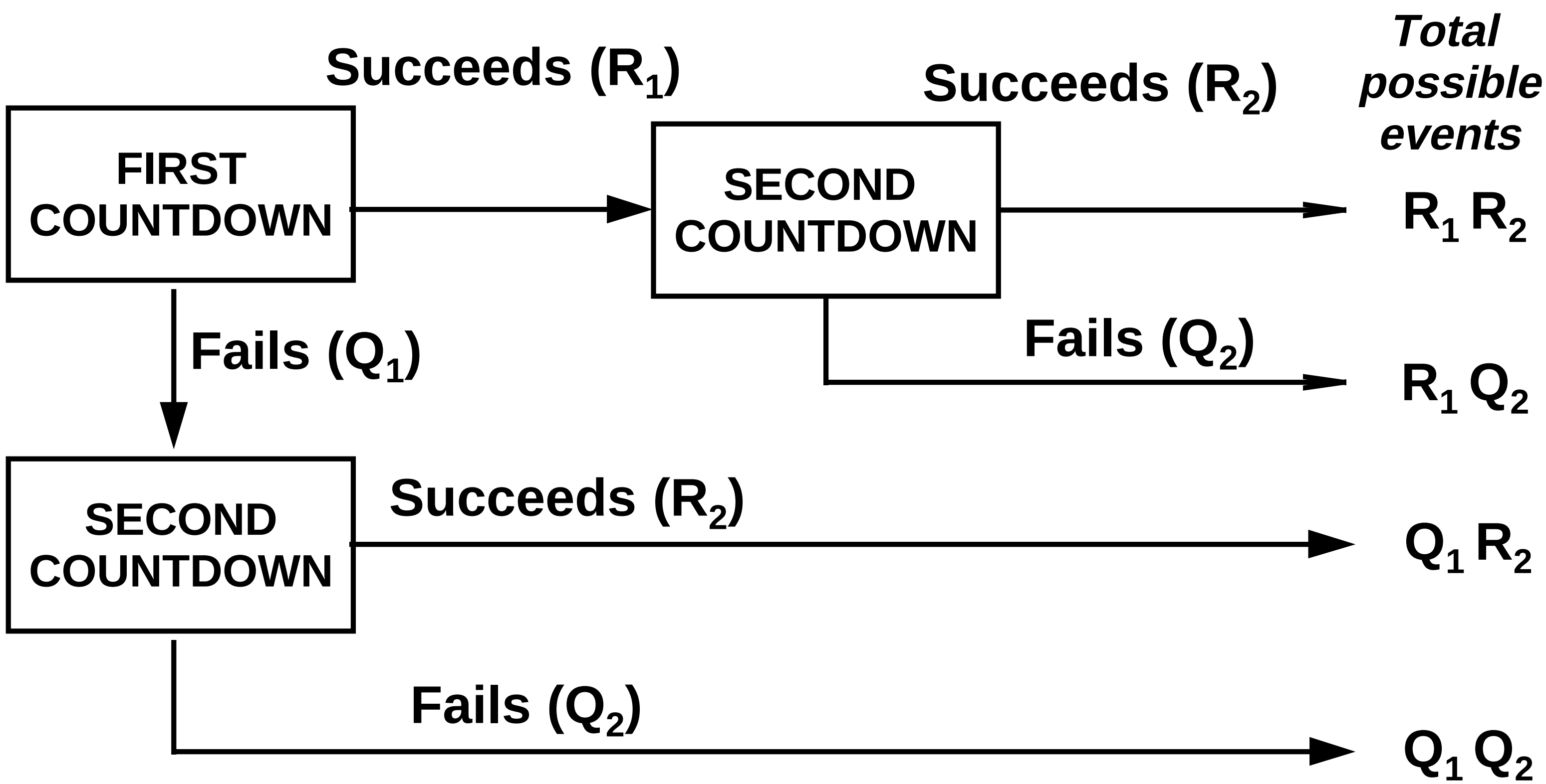
- **Theorem 2 - if R_1 is the probability that a first event will occur and R_2 is the probability that a second event will occur, the probability that both events will occur is R_1R_2.**

PROBABILITY THEOREMS

- **Theorem 3 - if R_1 is the probability that a first event will occur and R_2 is the probability that a second event will occur, and if not more than one of the events can occur (i.e. the events are mutually exclusive) the probability that either the first or the second but not both events will occur is $R_1 + R_2 - (R_1 R_2)$.**

ALL POSSIBLE EVENTS

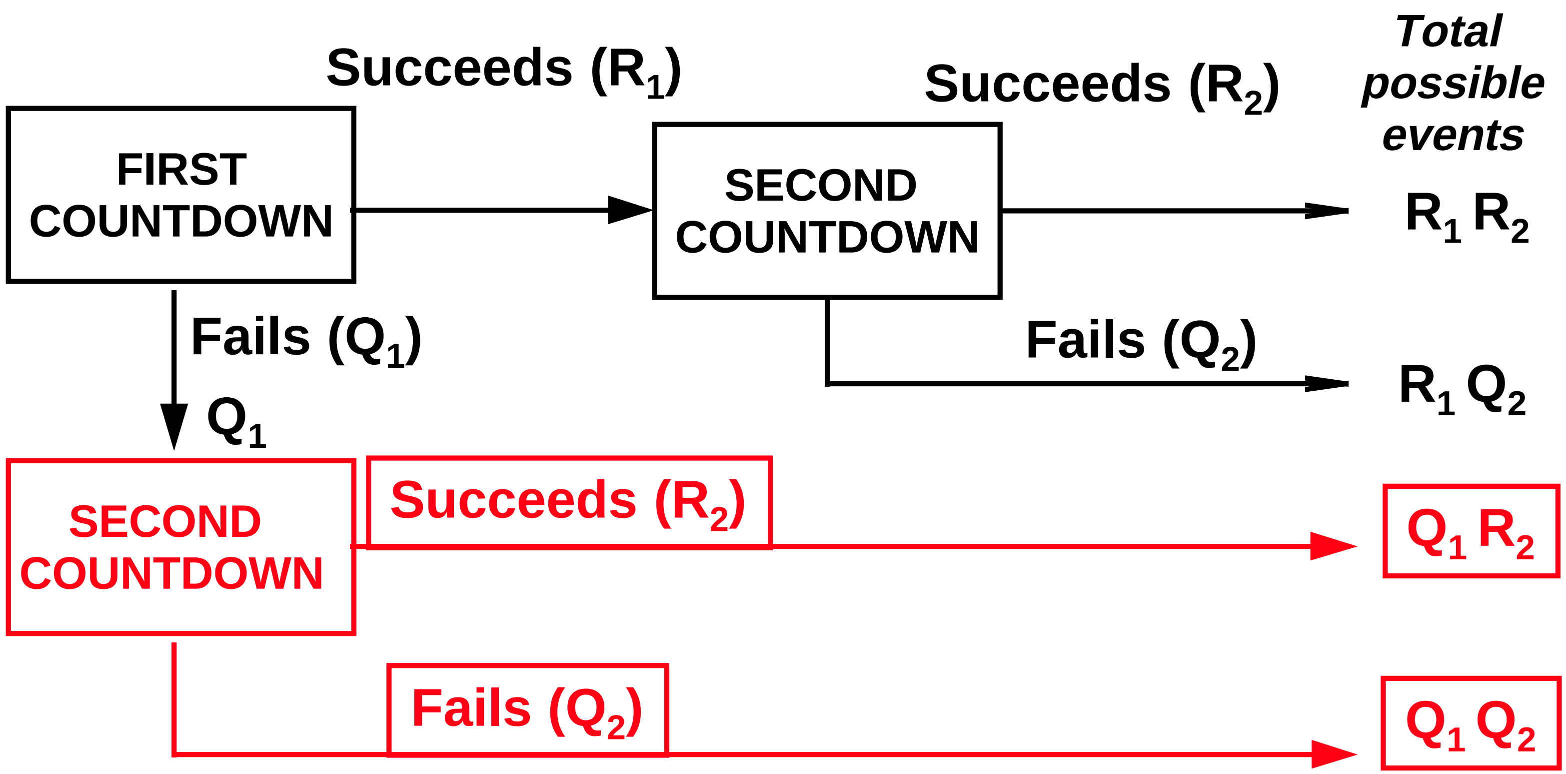
Two Countdowns Must Be Completed



ALL POSSIBLE EVENTS

Two Countdowns Must Be Completed

DISCARD EVENTS THAT DO NOT MEET CRITERIA



Example (con't)

- Q_1 first countdown fails
- R_1Q_2 first countdown succeeds and second fails
- R_1R_2 both countdowns succeed
- Since the three events are mutually exclusive theorem 3 applies. All possible outcomes must add to one (1).
- $Q_1 + R_1Q_2 + R_1R_2 = 1$
- If $R_1 = 0.9$, $Q_1 = 0.1$, $R_2 = 0.9$, and $Q_2 = 0.1$
- What is the probability of completing both countdowns?
- $R_1R_2 = 0.81$

CONCLUSION--PROBABILITIES

- **IN ANALYZING RELIABILITY DATA CARE MUST BE TAKEN TO CAREFULLY CHECK THAT EVENTS ARE INDEPENDENT AND MUTUALLY EXCLUSIVE.**
- **THE THREE THEOREMS ASSOCIATED WITH PROBABILITIES ARE:**
- **If the probability of success is R, the probability of failure ,Q is 1- R.**
- **If R_1 is the probability that a first event will occur and R_2 is the probability that a second event will occur, the probability that both events will occur is R_1R_2**
- **If not more than one of the events can occur (i.e. the events are mutually exclusive) the probability that either the first or the second but not both events will occur is $R_1 + R_2$**

RELIABILITY CONCEPTS and FAILURE PHYSICS:

TO UNDERSTAND RELIABILITY WE NEED TO:

- **UNDERSTAND RELIABILITY AS THE PROBABILITY OF SUCCESS AND AS THE ABSENCE OF FAILURE.**
- **PROPERLY DEFINE THE MISSION.**
- **PROPERLY DEFINE THE ENVIRONMENT.**
- **IDENTIFY FAILURE MODES.**
- **UNDERSTAND "INHERENT" RELIABILITY.**
- **UNDERSTAND HOW "EXTERNAL" FACTORS AFFECT RELIABILITY (AFTER DESIGN)**

Reliability as Absence of Failure

- **Consider this definition:**

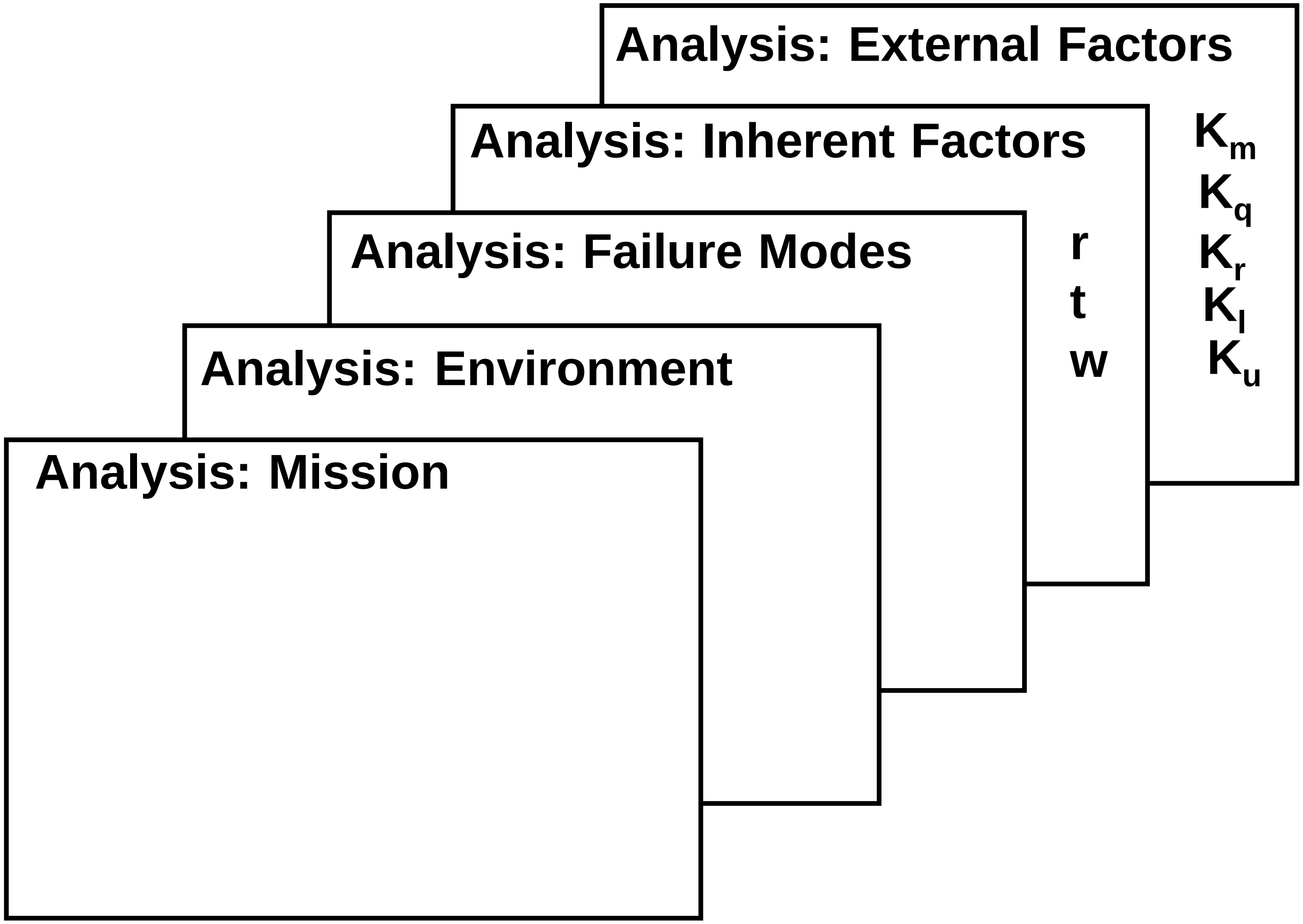
  Reliability is the probability that the critical failure modes of a device will not occur during a specified period of time and under specified conditions when used in the manner and for the purpose intended.

A clear definition of failure is needed.

Reliability as the Probability of Success

- **Classical Definition:**
- **Reliability is the probability that a device will operate successfully for a specified period of time and under specified conditions when used in the manner and for the purpose intended.**
- **Probability of success:**
- **Failures that keep the device from performing its intended mission will not occur.**
- **Emphasizes the need to define a successful mission.**

To Properly Assess Reliability We Need to Evaluate:



HOW RELIABLE IS A PRODUCT?
Failure Modes

- To know how reliable a product is or how to design a reliable product, we must know:
  - How many ways its parts can fail.
  - The types and magnitude of stresses that cause such failures.
- For many failure mechanisms we still often know:
  - Very little about why things fail.
  - Even less about how to control these failures.

Definitions of Failure Physics: FAILURE MODE

- **HOW THE FAILURE IS REVEALED.**
- **THE ABNORMALITY OF PERFORMANCE [OF THE PARTS] WHICH CAUSES THE PART [or COMPONENT] TO BE CLASSIFIED AS FAILED.**
  - **"VALVE FAILS TO OPEN"**
  - **"RELAY DOES NOT SWITCH TO NORMAL MODE"**
  - **"PRESSURE RELIEF VALVE FAILS TO OPERATE"**

Definitions of Failure Physics: FAILURE CAUSE

- **THE IMMEDIATE REASON WHY A COMPONENT FAILED.**
- **NOTE: THEIR MAY BE A HIERARCHY OF CAUSES!**
  - **THE VALVE FAILED TO OPEN BECAUSE THE SEAL EXTRUDED INTO THE OPENING.**
  - **THE RELAY DID NOT SWITCH TO NORMAL MODE BECAUSE OF TOO LOW A SIGNAL.**
  - **THE PRESSURE RELIEF VALVE FAILED TO OPERATE BECAUSE OF GALLING.**

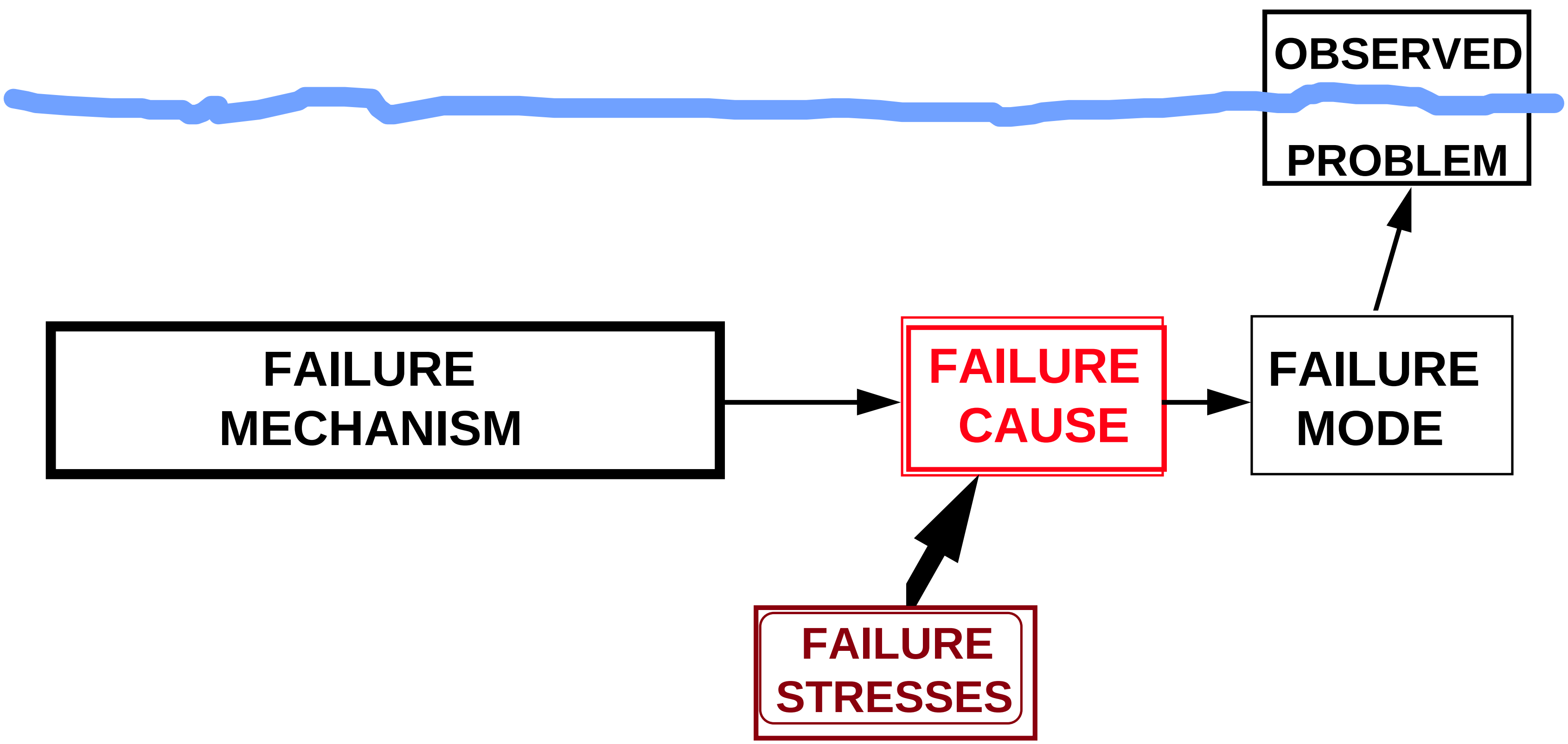
Definitions of Failure Physics: FAILURE MECHANISM

- **WHAT PRODUCES THE FAILURE MODE.**
- **THE FAILURE INDUCING AGENTS.**
- **THE PROCESS OF DEGRADATION, OR CHAIN OF EVENTS RESULTING IN A PARTICULAR FAILURE MODE:**
  - **CHEMICAL** **ELECTRICAL**
  - **FORCE** **TEMPERATURE**
  - **MULTIPLE** **NUCLEAR**
  - **OTHER**

Definitions of Failure Physics: FAILURE STRESSES

- What activates the failure mechanisms.
- Stresses or forces, such as shock or vibration, which induce or activate a failure mode.

THE PROCESS OF FAILURE



PRODUCT FAILURE MODES

CRITICAL FAILURES MAY BE CLASSIFIED AS:

- **RANDOM (CATASTROPHIC) PARTS FAILURES.**
- **TOLERANCE FAILURES.**
- **WEAROUT FAILURES.**

Learning From Each Failure

- When a product fails, a valuable piece of information has been generated.
- We have an opportunity to learn how to improve the product if we take the right actions.

Inherent Product Reliability

The product's potential reliability as described by the products documentation. It is the reliability *inherent* in the design drawings before the manufacturing process.

Design comes off the drawing board with the following:

$$R_D = Probability\ (r \cdot w \cdot t)$$

where

- R_D **= the probability of the design being successful.**
- r **= the event that random failure does not occur.**
- t **= the event that tolerance failure does not occur.**
- w **= the event that physical wearout does not occur.**

External Contributors to Product Failure - K Factors

$$R_{product} = R_D(K_q K_m K_r K_l K_u)$$

- **K factors denote probabilities that design-stage reliability will not be degraded by:**

  K_m **mfg., fabrication and assembly techniques**

  K_q **quality test methods and acceptance criteria**

  K_r **reliability fault control activities**

  K_l **logistics activities**

  K_u **the user or customer**

- **If each K factor equals 1 (the goal):** $R_{product} = R_D$
- **Note: any K factor can cause the reliability to go to 0.**

CONCLUSION: THE CONCEPTS OF RELIABILITY INCLUDE:

- **PROPERLY DEFINING THE MISSION.**
- **PROPERLY DEFINING THE ENVIRONMENT.**
- **IDENTIFYING WHAT FAILURE MODES CAN OCCUR (Distinguish between failure mechanism, failure cause, failure stress and failure mode as well as what the observed problem is.).**
- **UNDERSTANDING "INHERENT" RELIABILITY.**
- **UNDERSTANDING HOW "EXTERNAL" FACTORS AFFECT RELIABILITY (AFTER DESIGN)**

END; MORE>

EXPONENTIAL DISTRIBUTION & MTBF

CONSTANT FAILURE RATE (CFR)--DEFINITION

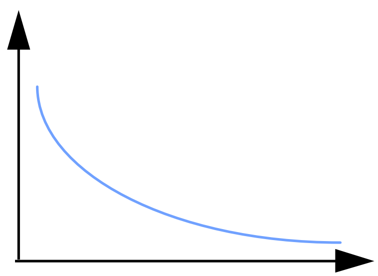
- The number of failures per unit of time or per unit of operation (distance, cycles, time, etc.). The failures occur at random times and at the same (constant) rate over the period of interest.
- THIS IS BASED ON THE EXPONENTIAL DISTRIBUTION

CONSTANT FAILURE RATE

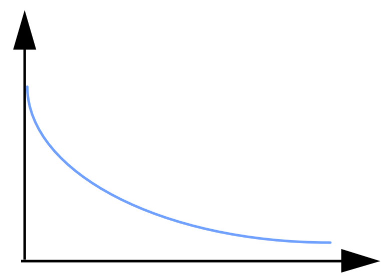
- **Failures occur randomly in time (but not necessarily from random causes).**
- **Failures occur randomly from part to part.**
- **This is also assumed to be the failure rate after initial burn in (and the rate before wearout).**

TYPE OF DISTRIBUTION

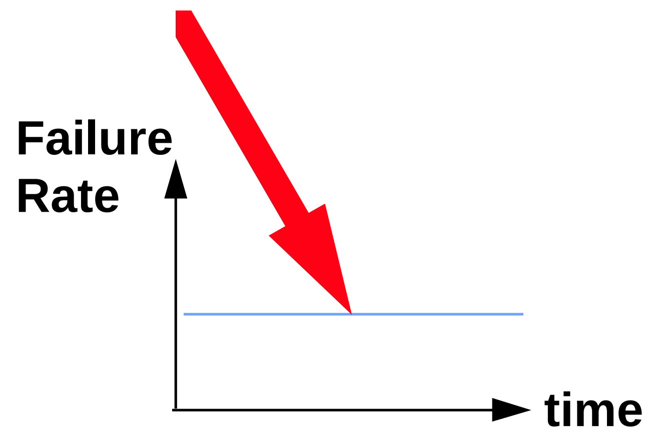
- The failure rate notation is lambda (λ) as used in the exponential distribution $e^{-\lambda t}$.
- This is the Hazard Function of the Exponential Distribution.



Probability Density Function



Reliability Function



Hazard Function

MAINTENANCE OF CFR SYSTEMS

- This represents the random catastrophic failure rate that occurs in so short a time that they cannot be prevented by scheduled maintenance OR
- This represents a complex non-repairable system OR
- This represents a complex system subject to repair and overhaul where different parts exhibit different patterns of failure with time and parts have different ages since repair or replacement.

Exponential Distribution and CFR Derived from Poisson Distribution

Definition Poisson Distribution:

$$P(x,t) = \{(\lambda t)^x \, e^{-\lambda t}\}/x!$$

where

λ **= average failure rate**

t **= operating time**

x **= observed number of failures**

Exponential Distribution and CFR Derived from Poisson Distribution

Development from Poisson

Using the Poisson Distribution for x = 0 (i.e. no failures)

$$P(0,t) = \{(\lambda t)^0 e^{-\lambda t}\}/0! = e^{-\lambda t}$$

Reliability becomes:

$$R = e^{-\lambda t}$$

Failure rate

- The failure rate represents random catastrophic part failures (not necessarily from random causes) that are random from part to part.
- Failure rates are usually expressed as the number of failures per 10^x hours or cycles.
- Some government documents express λ in percent failures per 10^3 hours.

Reciprocal of Failure Rate

- **For the exponential distribution the reciprocal of failure rate is Mean Time Between Failure**

$$MTBF=(1/\lambda)\ \underset{0\ to\ infinity}{Integral}\ e^{-\lambda t}dt=(1/\lambda)(e^{-\lambda t})\Big|_{0}^{infinity}$$

$$= -(1/\lambda)\{(1/e^{infinity})-(1/e^{0})\}=-(1/\lambda)(0-1)=1/\lambda$$

- **Substituting** $MTBF$ **for** $1/\lambda$ **gives:**

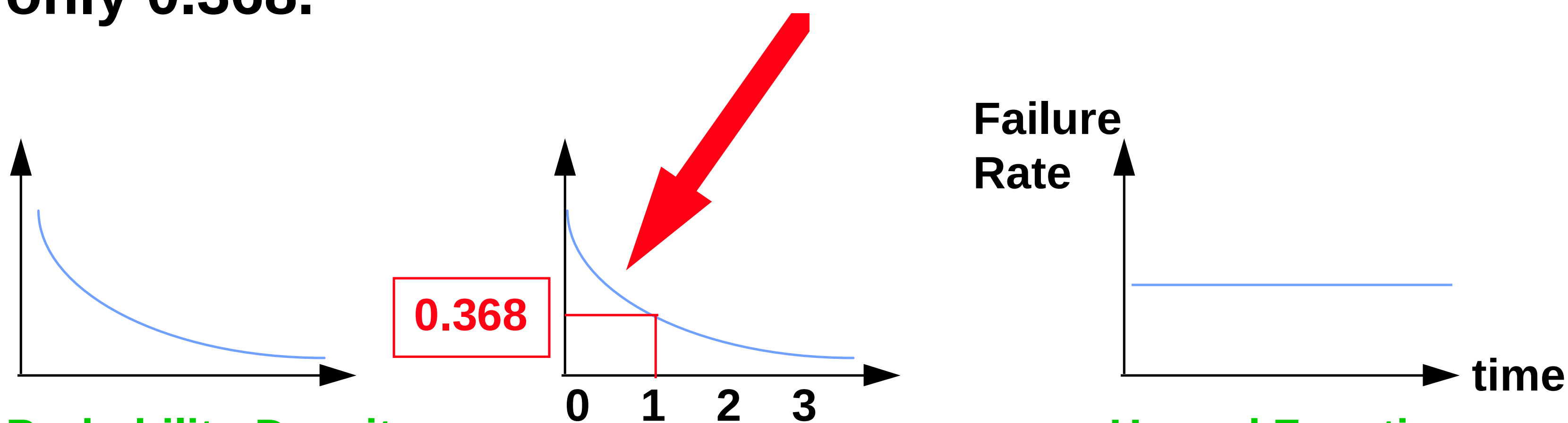
$$e^{-\lambda t} = e^{-(t/MTBF)}$$

Reliability at MTBF

- When operating time = $MTBF$ the Reliability is

$$e^{-(OPERATING\ TIME\ /\ MTBF)} = e^{-1} = 0.368 = 36.8\%$$

- Thus when the operating time reaches the calculated MTBF, the probability that the unit is still operating is only 0.368.



Probability Density Function

Reliability Function

Hazard Function

MEAN TIME BETWEEN FAILURES (MTBF)

- **FOR THE EXPONENTIAL DISTRIBUTION the MTBF = 1/λ**
- **REMEMBER: This is a constant failure rate!**
- **UNITS: Hours, Cycles, Miles etc.**
- **a.k.a.**
  - **MCBF (Mean Cycles Between Failures)**
  - **MTTF (Mean Time To Failure) for a non repairable device.**

CALCULATION OF MTBF
(an approximation from test data)

- MTBF= (Total test hours)/(Total observed failures)
- EXAMPLE: If 100 cars are run for 100 hours and 17 fail (have a major failure which prevents them from completing the course) then: “MTBF”= ~ (100 x 100)/ 17 = 588.24 hours.
- (assume cars are repaired and continue to run to complete the 100 hours).
- EXAMPLE: If these 100 cars are run at 60 miles per hour for the 100 hours and 17 fail (have a failure which prevents them from completing the course) then: "MTBF"=100 x 60 x 100 / 17 = 35294 miles.

CONCLUSIONS - MTBF

- **THE FAILURE RATE OF A COMPLEX SYSTEM IS USUALLY CONSIDERED TO BE CONSTANT.**
- **THE FAILURES OCCUR AT RANDOM TIMES AND AT THE SAME CONSTANT RATE OVER THE PERIOD OF INTEREST.**
- **THE CONSTANT FAILURE RATE IS BASED ON THE HAZARD FUNCTION OF THE EXPONENTIAL DISTRIBUTION (AFTER BURN-IN AND BEFORE WEAROUT).**

$$MTBF = 1/\lambda$$

$$MTBF = \sim TOT.TEST\ HRS.\ /\ TOT.FAILURES.$$

END